Pushing Sensors Close to Process

Technologies Supporting Krafla Magma Testbed and Supercritical Geothermal

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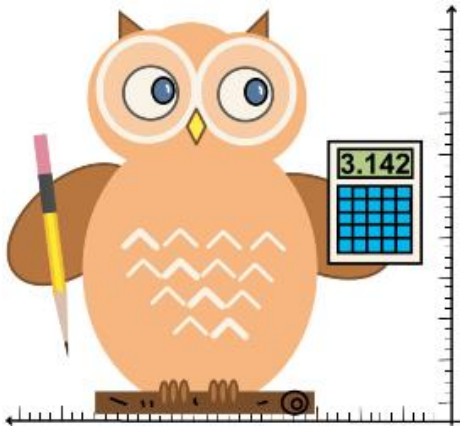
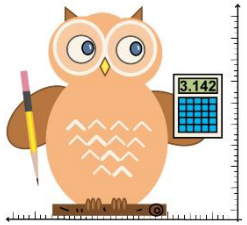
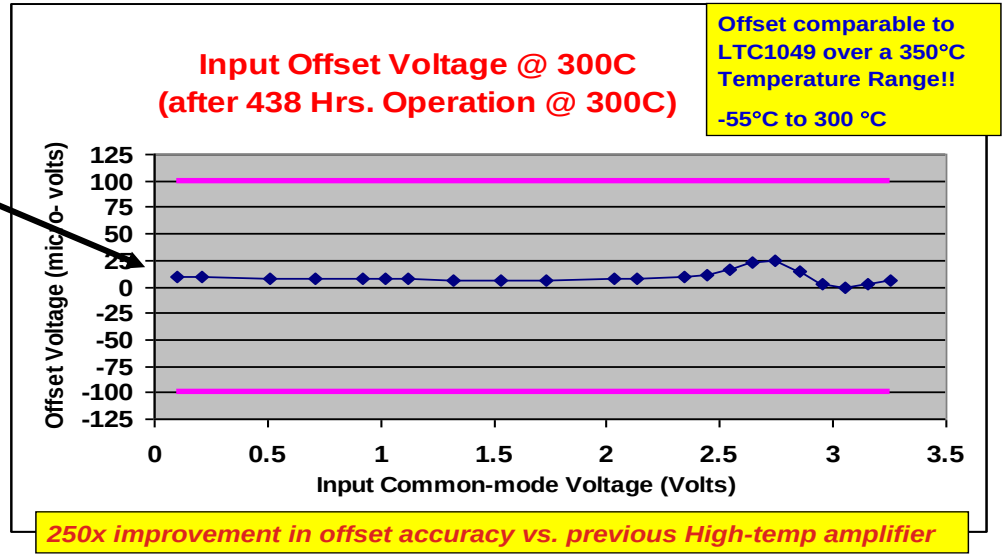
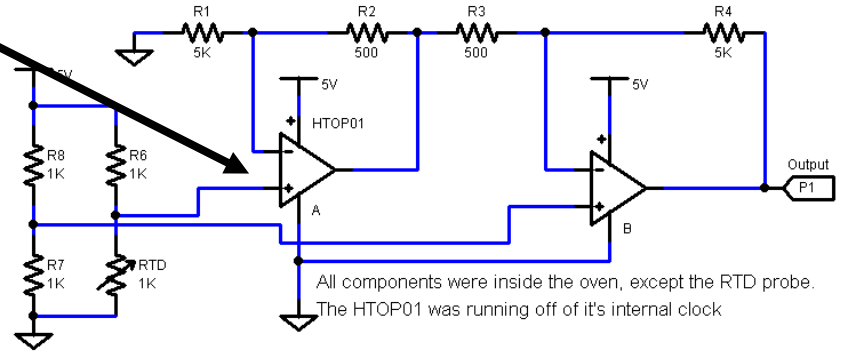


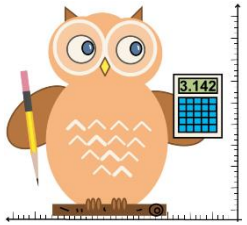


HT SOI Precision Amplifier

- Achieved 18-bit dynamic range
- Achieved high input impedance:
  - < 1nA input offset current at 225°C
  - Ideal for pressure, strain or **thermocouple measurements**
  - Input impedance is in the Gig ohms
- **Demonstrated operation:**
  - **-55°C to 375°C (inside a lab)**
- **This test performed at Sandia National Lab for Honeywell SSEC**

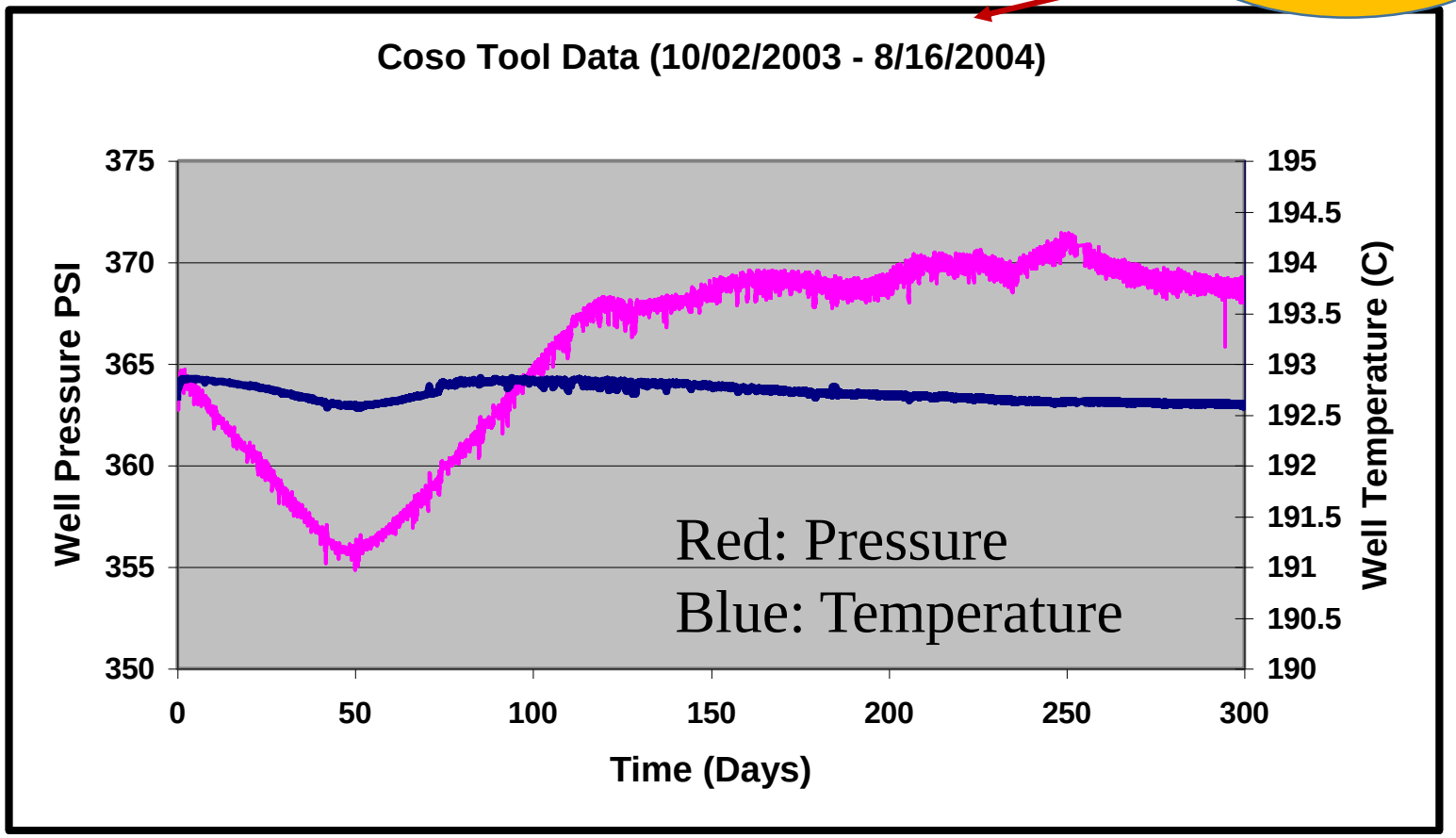






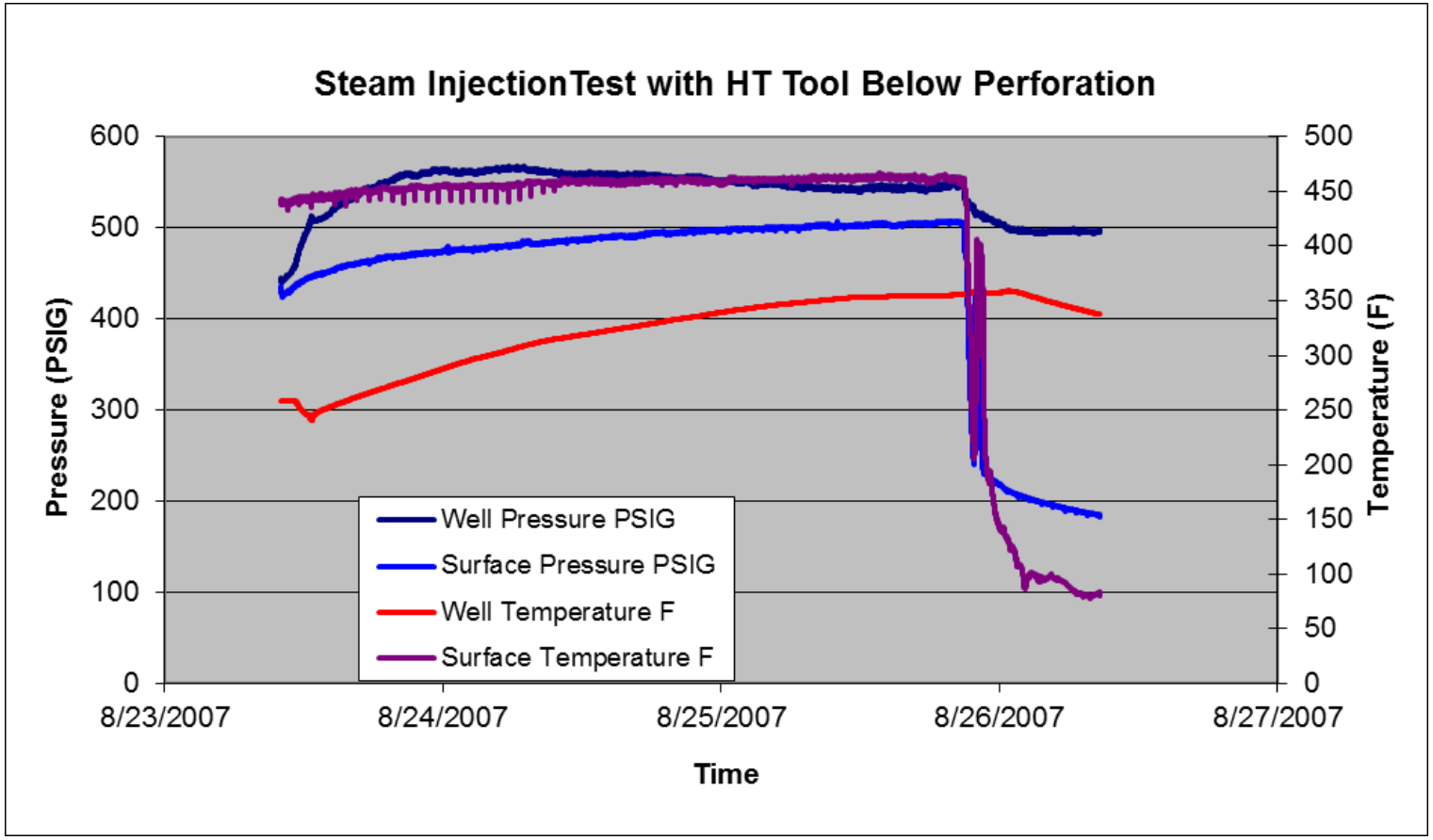
First Year of Two at 193C Geothermal Well Monitoring

Notice the dates!



Pressure noise is mostly caused earth tides in the reservoir.

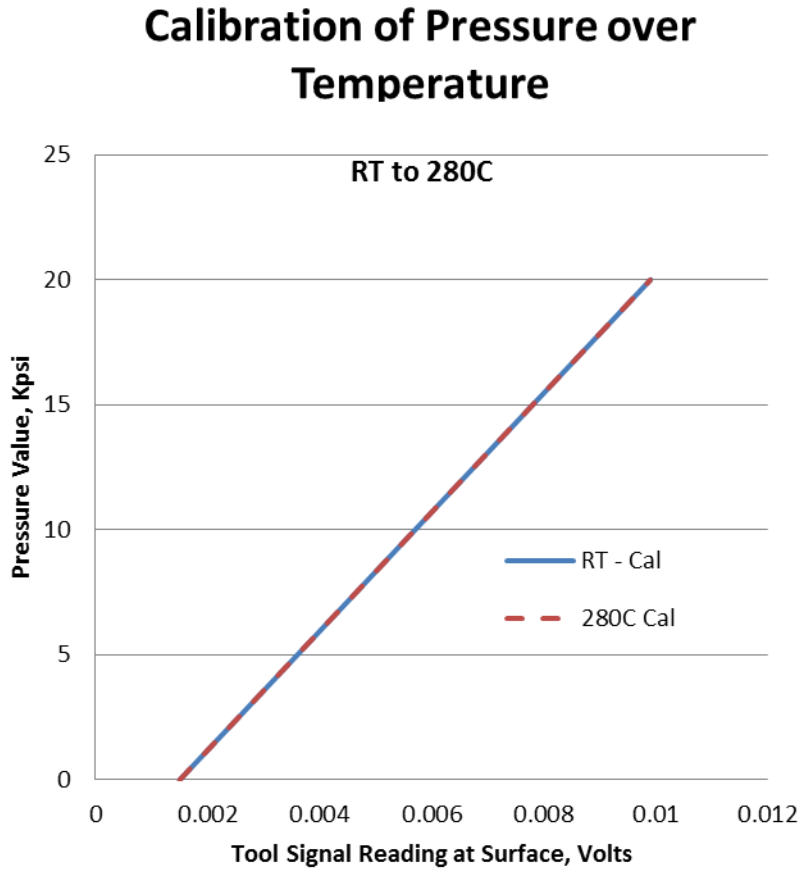
Two Tools, Two Wells for One Year

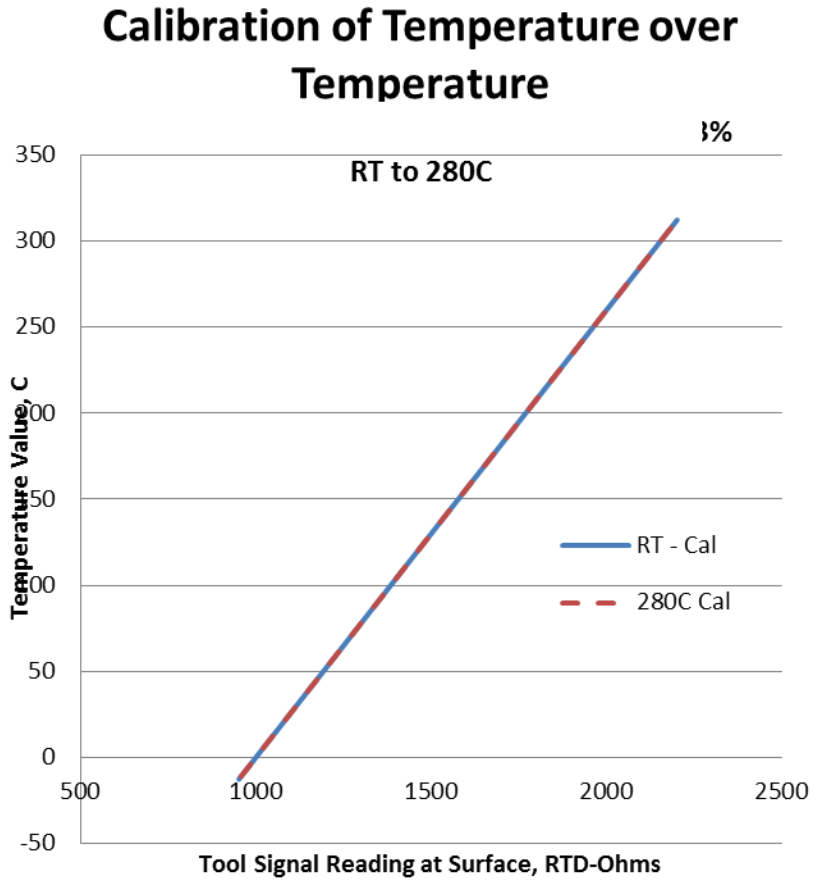


In 2007-2008, this was a huge success. Our HT SOI tool monitoring a steam injection well over 12 months without failure tracking the reservoir in two wells. These wells see a high number of temperature cycles up to 235C.

Breakthrough in Self-Compensation

No Computer Temperature Compensation was applied to the Calibration Data Below!

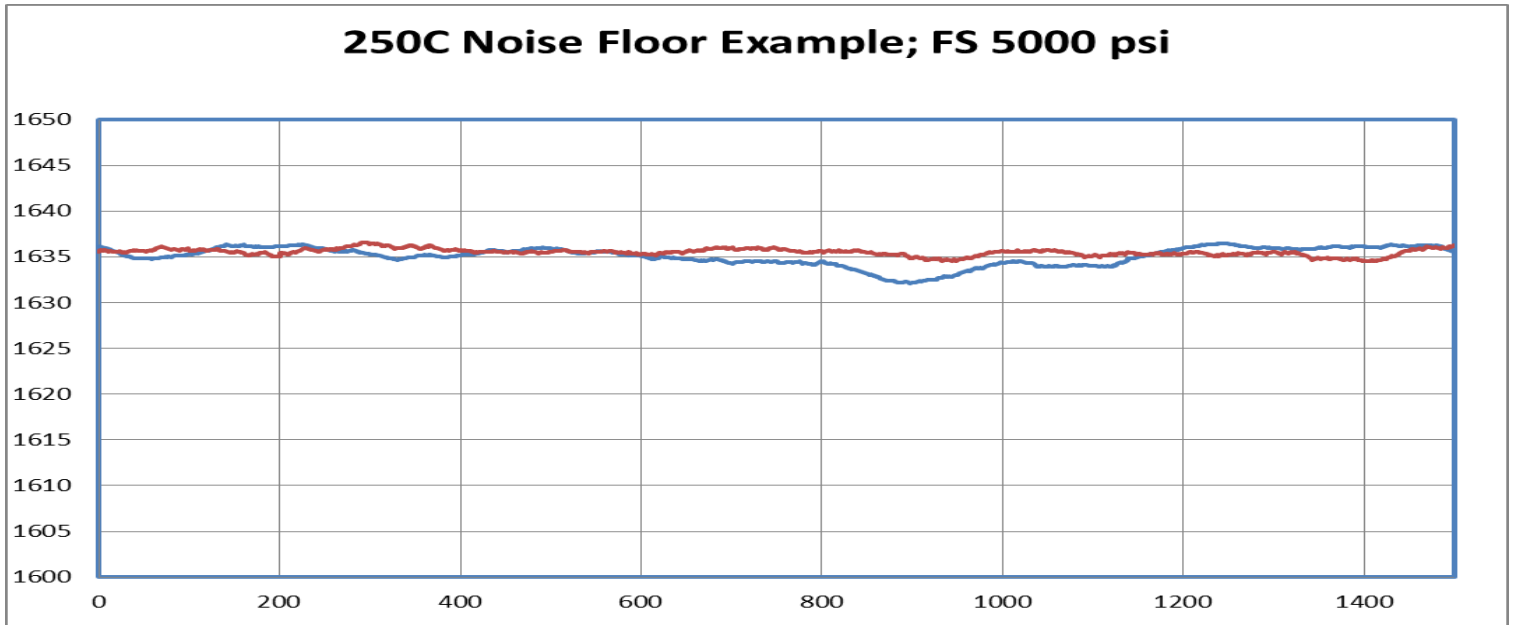


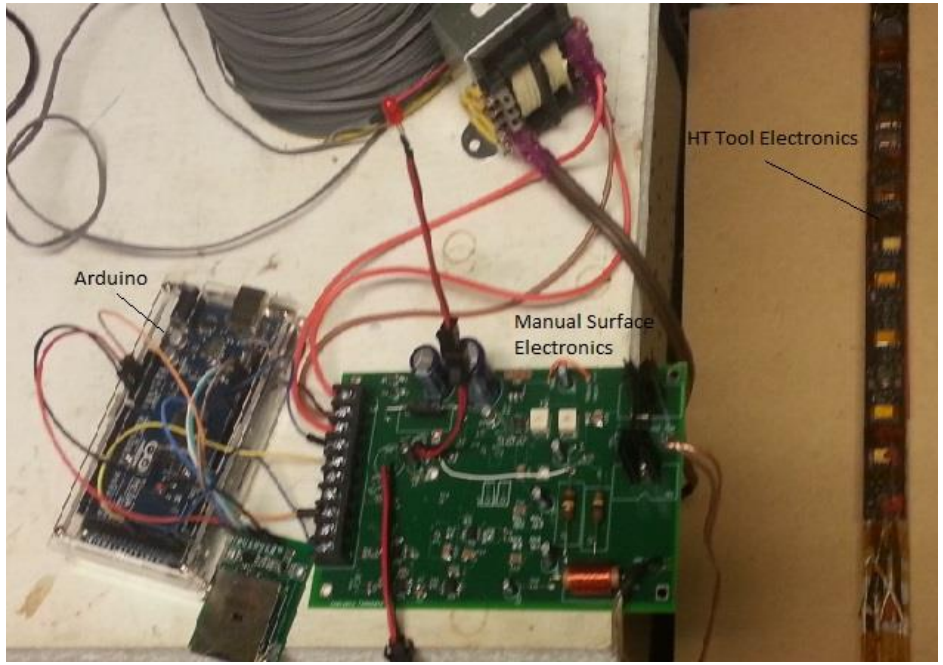


Even standard flasked tools use long polynomial temperature correction algorithms! Our self-compensation is done downhole allowing our tool to stay in calibration longer and over extreme temperatures found in Geothermal wells.

HT SOI Noise Floor

- The new On Measurement* surface electronics uses the Arduino
  - Greatly reduces cost of the surface system
  - Anyone can program it
- Below is the noise floor at 250C
  - Blue trace is signal + power on 1 wire
  - Red trace is signal only, power on second wire



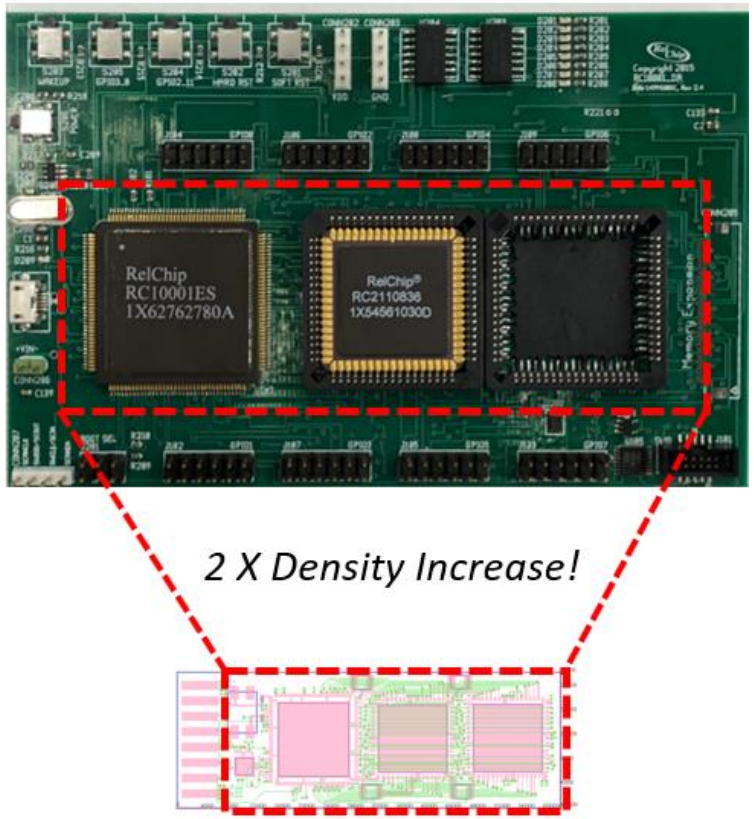


*www.onmeasurement.com

Book: “Arduino for Projects in Scientific Measurement” by Randy A. Normann

Latest HT SOI Technology

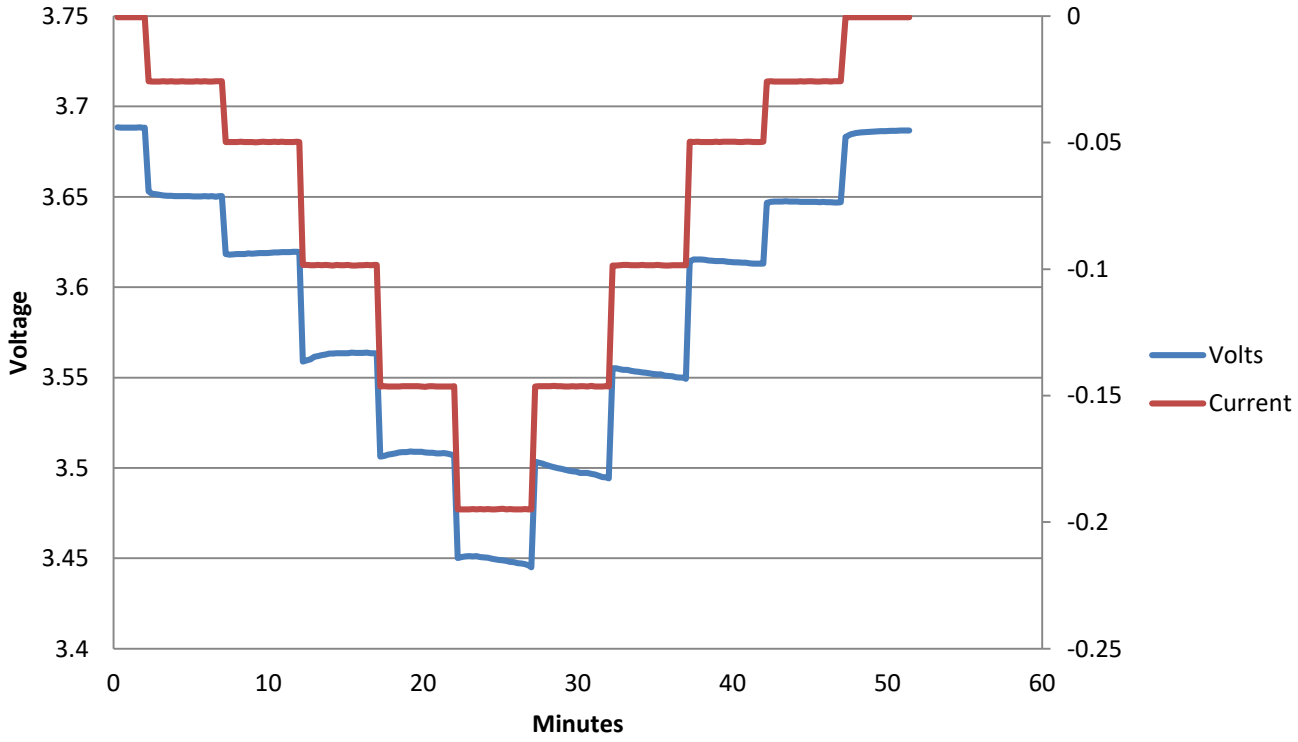
- A 32Bit, HT SOI Microcontroller from RelChip
- The Perma Works tested version (larger than shown) run over 300C
- The MCM shown is from RelChip & Ozark IC technology
- MCM 0.886 inches wide by 2.48 inches long
  - Includes uP, memory and digital clock



https://www.relchip.com/

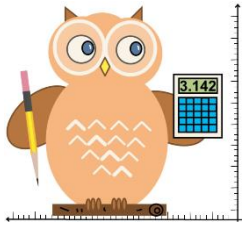
Solid-State Batteries are HT and Safe!

Battery IR <1.5Ohms



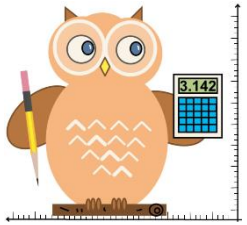
225C Test Charge and Discharge

- No liquid components
- No lithium
- Higher Internal Resistance (IR) than lithium
- Safe up to 500C
- **Rechargeable**
- **Not yet in commercial production**
- Test to the left is a discharge/charge of 1 “C” sized cell



500C SiC Electronics

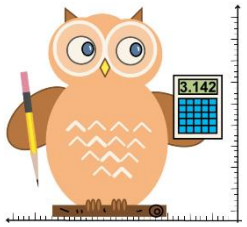
- Silicon Carbide (SiC) basic electronic devices are commercially available
  - Mostly for the power electronic industry not high temperature
  - Improve performance in power applications over Silicon
  - Can be packaged for 500C operation
    - Limited operating time ~1000hrs
    - Has been shown to operate up to 1400F
- SiC is missing some important elements needed for downhole electronics
  - No voltage reference
  - No high density devices as microprocessors

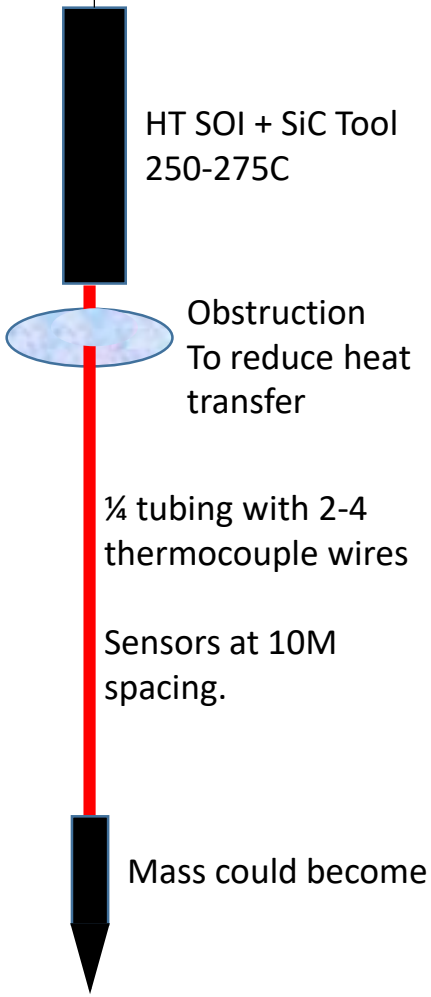


Two Government HT Electronic Research Groups

- NASA Glenn
  - NASA has a user SiC fabrication facility where circuit designers can build their own 500C electronic components using CAD
  - NASA can be contracted directly by private companies to develop new 500C SiC electronics
  - NASA has a 600C SiC pressure transducer but only rated up to 600psi
  - Contact: Phil Neudeck, philip.g.neudeck@nasa.gov
- Fraunhofer eHarsh Program
  - Future sensors ceramic/MEMEs for control systems up to 500C
    - Temperature and Pressure
  - HT SOI electronics up to 300C with considerations for geothermal applications
    - Future MEMS 300C accelerometer
  - Contact: Holger Kappert, holger.kappert@ims.fraunhofer.de

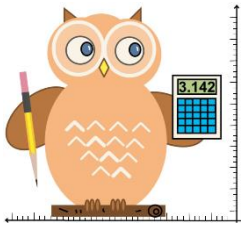
Well Temperature Gradient Monitoring



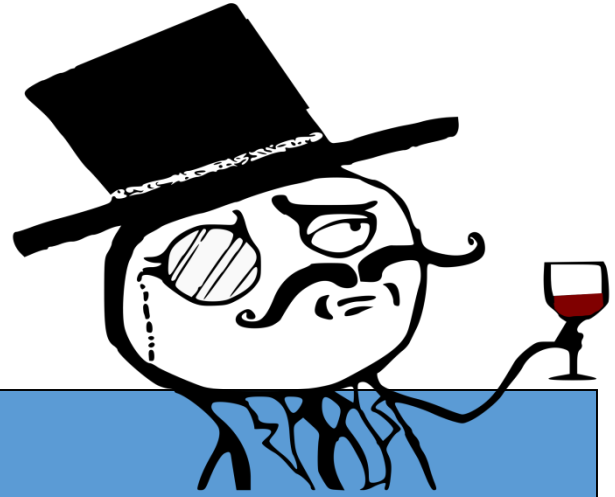


- Open well head required for deployment
- The tool assembly is deployed with 3 wires inside tubing. This allows for month or years of service.
- HT SOI tool is produced without organic materials, all metal-to-metal seals
- 100% of the components inside the tool have been hydrogen tested at temperature
- ¼ inch tubing and thermocouple is 100-300 meters long
- At installation, we can pour sand or other material to seal in the thermocouples into the bottom hole.
- Track multiple thermocouples bottom hole temperature with 10M spacing for a gradient measurement
- If needed, we can consider a larger surface tubing to provide cooling water to cool the well at the location of the HT SOI tool to maintain <275C

Conclusion



- There are complete HT electronic solutions up to 275C for most well monitoring applications in geothermal.
  - Thermocouples are rated for magma temperatures
  - Pressure transducers can be found up to 600C but with low pressure rating
- There is a future in 500C SiC electronics but currently only a few components which could be used as sensor signal amplifiers.
- New solid-state batteries and HT electronics enable Dewar flasked geothermal logging tools to penetrate deeper in to supercritical wells.

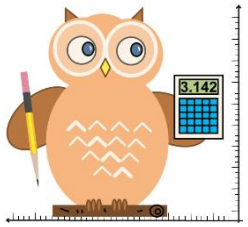


Thank You

Enjoy the Conference

I will be returning to Paris* after this presentation.

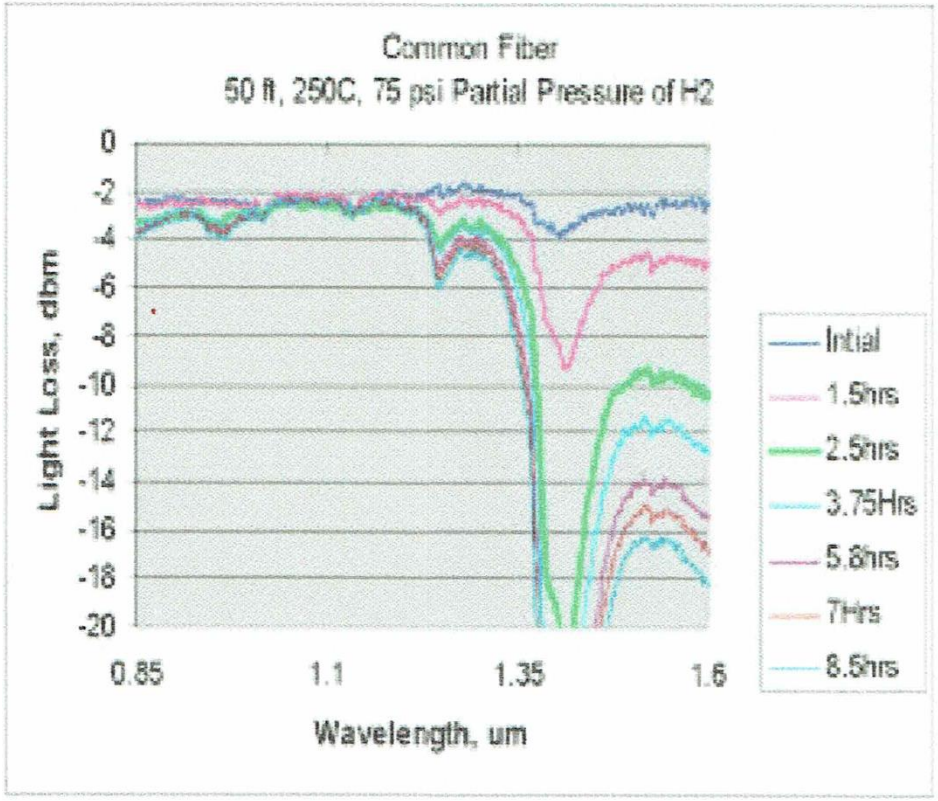
* **Paris, Texas**



Geothermal Fiber DTS Measurements

- In the 1990s, DTS measurements were seen as the holy grail of geothermal well monitoring – “Nothing but glass” was the selling point.

- In truth, fiber more than glass. It requires doping to ease manufacturing and to create a favorable index of refraction.
- Free hydrogen is created in all geothermal wells. Hydrogen will bond within the glass, creating a hydroxyl, OH.
- The OH darkens the fiber as seen in the plot to the right. This was a HT polyimide buffered fiber. The fiber was only 200ft long.
  - At 250C and no H2, no light loss. However, within a few hours with a small partial pressure of 5% H2, the fiber starts darkening.
  - Free hydrogen at 250C, is the superman of atoms; it can not be stopped. Not by stainless steel tubing, not by gold cladding, not by any known material.
- The author’s only known successful deploy of DTS fiber for monitoring a hot well was behind the casing, away from the fluid.



The Acoustic Process Concept